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Urban and rural sanitation in the Solomon Islands: How resilient are these to extreme weather events?

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Abstract

The Solomon Islands, like other small island developing states in the Pacific, face significant challenges from a changing climate, and from increasing extreme weather events, while also lagging behind the rest of the world in terms of drinking water, sanitation and hygiene (WaSH) services. In order to support planning for the implementation of national WaSH strategies and policies, this study contextualizes representative urban and rural baselines for Sustainable Development Goal (SDG) 6 ("by 2030, achieve access to adequate and equitable sanitation and hygiene for all and end open defecation"). We highlight specific threats to the current sanitation services under extreme weather events such as flooding and drought, both of which are commonly observed in the country, and provide suggestions for structural improvements to sanitation facilities to increase resiliency. As the first detailed nationally representative cross-sectional sanitation study in urban and rural areas in the Solomon Islands, the results of this paper inform national WaSH policy, strategic planning and programming by the Solomon Islands Government and stakeholders.

Highlights

- First representative water, sanitation and hygiene study in the Solomon Islands.
- Inadequate sanitation and open defecation are more widespread in rural than in urban areas.
- Our baseline data shows that the sanitation situation is worse than presented in official country-wide estimates (JMP).
- Assessment of vulnerability, adaptability and resilience of sanitation infrastructure during flooding and drought.
- Relevance for national policies, planning and programming.

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Competing interests

The authors declare that they have no competing interests.

MAIN TEXT

1 Introduction

Small Island Developing States (SIDS) such as Pacific Island Countries (PICs) are environmentally, socio-culturally, and highly economically diverse, and face significant challenges from a changing climate. PICs are vulnerable to extreme weather events such as tropical storms, drought, heavy rainfall, and flooding, as well as longer-term hardships related to sea level rise (IPCC 2014). PICs are inhabited by predominantly rural populations with limited resources and market access, and diverse cultures, all of which make the provision of drinking water, sanitation and hygiene (WaSH) services difficult (Hadwen et al. 2015, MacDonald et al. 2017).

PICs lag behind the rest of the world in terms of sanitation services, and marked disparities exist between urban and rural areas (WHO & UNICEF 2017). Inadequate sanitation poses a serious contamination threat to an already limited freshwater supply (Merson et al. 1977, Mosley et al. 2004, White et al. 2008), and increases the vulnerability of the communities who rely on it (Anthonj & Falkenberg 2019). Combined with poor hygiene, such conditions expose community members to infectious disease transmission (Bukenya & Nwokolo 1990, Greenwell et al. 2013), thus severely impairing human health, well-being and socio-economic development (Bartram & Cairncross 2010, Black et al. 2003, Fewtrell et al. 2005).

In the Solomon Islands, while the largest share of the population lives in rural areas (75%), urbanization is occurring at a rapid pace. By 2050, the urban population is projected to reach 40%. This rapid growth of urban areas increases the strain on urban planning, water, sanitation and sewerage services, health service provision and general infrastructure (Anthonj et al. 2014, Haberkorn 2008, SIG 2009, Schrecongost & Wong 2015, Schrecongost et al. 2015, UN-Habitat 2012). The Solomon Island Government National WaSH Policy has the vision that "all Solomon Islanders will have easy access to sufficient quantity and quality of water, appropriate sanitation and will be living in a safe and hygienic environment by 2024" (MHMS 2014). Achieving this aim is challenging, considering the markedly low access to a sanitation service, the lack of a hygiene policy and the low coverage of basic drinking water services (Anthonj et al. 2018, Shields et al. 2017).

The country is vulnerable to climate change (Shields et al. 2016), impacted by sea level rise (Albert et al. 2016), and faces threats from increasingly frequent extreme weather events, particularly tropical cyclones and heavy rains resulting in flash floods (Hadwen et al. 2015), as well as decreased rainfall and resulting drought (Hadwen et al. 2015, Connell 2015). Such events can damage sanitation infrastructure (MacDonald et al. 2017, Howard & Bartram 2010) and threaten the sustainability of development programs. The literature base discussing how climate change affects sanitation infrastructure is very limited (Howard et al. 2016, Luh et al. 2017, Sherpa et al. 2014), even though the impacts will likely be just as significant as those on water infrastructure (Howard et al. 2016) and may contribute or compound the threats to drinking water supplies (Luh et al. 2017). In the Solomon Islands, in the light of vulnerability to climate change and related extreme weather events, poor sanitation planning that is not adapted to increased likelihood of extreme weather events will likely pose serious threats to their already fragile freshwater resources (Merson et al. 1977, Mosley et al. 2004).

"Ensuring availability and sustainable management of water and sanitation for all" is a priority in global development policy agendas, reflected in the United Nations General Assembly's recognition of the human right to water and sanitation (Resolution 64/292) (UN 2010), as well as in the Sustainable Development Goals (SDGs) through Goal 6 (UN 2015). To support planning for the implementation of national strategies and policies, and to create a representative baseline for SDG 6.2 reporting ("by 2030, achieve access to adequate and equitable sanitation and hygiene for all and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations"), two baselines, including rural and urban household data collection, were conducted in the Solomon Islands by UNICEF Pacific (Anthonj et al. 2018, Shields et al. 2017,).

Based on these two datasets and the comparative urban / rural analysis of sanitation service levels and infrastructure, we

(i) contextualize our sanitation results in terms of their assumed resilience (vulnerability and assumed adaptability) under two extreme weather event scenarios, increased rainfall and decreased rainfall, and
(ii) compare our baseline data to regional estimates for SIDS and PICs in Oceania, and
(iii) identify gaps and potential for improvement, informing national WaSH policy, strategic planning and programming.

This is the first paper to examine the climate resilience of sanitation in a SIDS and PIC. The analysis may be used to assist in the planning of future interventions, and it provides suggestions for renovations and adaptations to current sanitation infrastructure to extreme weather events.

2 Material and methods

2.1 Country context

2.1.1 The Solomon Islands: A Small Island Developing Country in the Pacific

The Solomon Islands, an archipelagic state situated in the South West Pacific Ocean, comprises six major islands and nearly 1,000 smaller islands, of which approximately 350 are inhabited, extended over approximately 28,400 km^2 (Figure 1). About 75% of the population live in rural areas (Anthonj et al. 2018) with approximately 20 people per square km, making it one of the least densely populated areas in the world (Schwarz et al. 2011).

Figure 1

The capital, Honiara, is located on Guadalcanal, the largest island. The country has nine provinces and is home to approximately 600,000 inhabitants (18.1 people/km^2).

2.1.2 The population and household structure of the Solomon Islands

As one of the Pacific's poorest countries, the Solomon Islands mainly relies on subsistence farming and struggles with poor infrastructure, limited labour skills, high utility costs, land tenure issues, and limited public administration and financial management capacity (DFAT 2018), compromising their ability to provide public services to the small and geographically dispersed population. Households in the Solomon Islands are mainly headed by men (75%), both in rural (81%) and in urban areas (66%), and household sizes are larger in urban (mean=7) than rural areas (mean=6) (Table 1) (Anthonj et al. 2018, Shields et al. 2017).

2.1.3 Sanitation and hygiene in urban and rural areas of the Solomon Islands

An often-stated obstacle to improving WaSH services in PICS relates to their isolated geography and the remoteness of the communities, which can create a more pronounced rural-urban disparity (Clarke et al. 2014, MacDonald et al. 2017, Hadwen et al. 2015). Based on the analysis preceding this paper (Supplementary Files 1-3, Anthonj et al. 2018, Shields et al. 2017), significant rural-urban inequalities in sanitation services, child faeces disposal and handwashing services, exist in the Solomon Islands.

Urban-rural inequalities in sanitation access in the Solomon Islands are particularly striking, with significantly greater access to sanitation services amongst urban (81%) compared to rural (20%) households. While in rural areas, flush toilets to pit latrines / drums (7%) and, pit latrines without slab / open pit (5%) are common among households that have sanitation facilities, urban households mainly have flush toilets to septic tanks (44%) (Figure 2, Supplementary File 1).

Figure 2

Quality of sanitation services amongst households with sanitation access is markedly uneven between rural and urban populations with significantly inferior sanitation services in rural areas. Most urban households (68%) have a basic sanitation service, while only 14% of rural households have a basic sanitation service. Access to sanitation facility, sanitation service levels, toilet ownership, cleanliness, happiness with the sanitation facility and use significantly differ between rural and urban areas, and the urban sanitation situation is generally better than the rural sanitation situation (Supplementary File 2).

Open defecation is practiced in 80% of rural households, and in 19% of urban households (Figure 3). High rates of open defecation, as we found in rural areas of the Solomon Islands, are likely to have detrimental effects on the already fragile and scarce freshwater resources available (Carpenter & Jones 2004, Hadwen et al., 2015).

Figure 3

Access to a handwashing facilities is significantly higher in urban (75%) than in rural (51%) households. Fewer rural (16%) than urban households (43%) have a basic hygiene service (Supplementary File 3) (Anthonj et al. 2018, Shields et al. 2017).

2.1.4 Climate and extreme weather events in the Solomon Islands

The tropical equatorial climate is characterized by fairly constant high temperatures (~27 °C), high humidity (80%) and abundant rainfall in most areas throughout the year (3,000 to 5,000 mm per annum). Rainfall patterns vary between locations, topographical gradients, and according to the season (MECDM 2012, MECDM 2018). The rainy season, within which on average almost 70% of the yearly total rain falls (~1,800 mm), lasts from November to April, and during this time, most flooding takes place as well. The dry season (~600 mm) lasts from May to October. Most rain falls from January to March, during the West Pacific Monsoon, which feeds the South Pacific Convergence Zone, and Intertropical Convergence Zone, which lies closest to the Solomon Islands during that time of the year. The far east of the country receives more precipitation during the year (280 to 420 mm per month). Rainfall in the Solomon Islands varies from year-to-year, and is strongly influenced by the El Niño-Southern Oscillation, particularly in the rainy season, as well as by La Niña. The winds are seasonal as well, and typically not as strong as in other Pacific regions further South or East (MECDM 2012). A number of tropical low pressure systems occur in each year's rainy season, but relatively few of these develop into tropical cyclones, and when they hit the Solomon Islands, they are usually in the early stage of their life cycle and less damaging than elsewhere in the South West Pacific. Nevertheless, resulting flooding and winds caused loss of lives, and severe damage to infrastructure, water supplies, and agriculture (MECDM 2018).

2.2 Survey instrument design and testing

Structured surveys were programmed into the Akvo FLOW mobile data collection tool which allowed data to be collected using smart phones, uploaded directly into a cloud-based database. The surveys covered sanitation access, quality and type of sanitation infrastructure, cleanliness, privacy and security, use of sanitation facilities, disposal of child faeces, hygiene access, and diarrhoea prevalence in the three days preceeding the survey. The questionnaires were developed within the Rural WaSH program within the Solomon Islands Ministry of Health and Medical Services (MHMS) Environmental Health Division (EHD), with input from the broader WaSH sector in the Solomon Islands, and reviewed by the National Statistics Office, WaterAid and UNICEF.

Prior to data collection, trainings of enumerators and team supervisors were conducted by MHMS, WaterAid (for the rural baseline only) and UNICEF. The two-week training covered planning of data collection, familiarization with the use of the mobile tool (AkvoFlow) by practical exercises, familiarization with the survey, pre-test of survey instruments, training in the sampling methodology of households, as well as reporting, supervision and information management.

2.3 Sampling

The sample designs for the urban and rural baseline surveys were developed in collaboration with the Solomon Islands National Statistics Office. The samples were designed to be nationally representative (Figure 1).

Enumeration areas (EAs) were the foundation of sampling. EAs correspond to the national population and housing census (SIG 2009) which, for field operational purposes, the whole country was divided into 1,344 enumeration areas (EAs), defined within the ward boundaries.

2.3.1 Rural areas

In rural areas 79 enumeration areas (EAs) out of the total 1,061 rural EAs in the Solomon Islands were sampled. EAs were then selected using the probability proportional to size method in each stratum (province). The selection was done using a fixed interval with a random start point. Within each EA, twenty households were randomly surveyed, resulting in a total of 1,597 households.

2.3.2 Urban areas

The sampling target for urban areas was 108 enumeration areas out of the total 283 urban EAs; 54 EAs in the Greater Honiara area and 54 EAs elsewhere. In the Greater Honiara area, 54 EAs were selected using the probability proportional to size method. In other urban areas, 54 EAs were selected due to the small populations. Eleven households per EA were randomly selected and out of those, ten were surveyed, resulting in a total of 1,062 households. The capital Honiara, although located in Guadalcanal, was sampled separately from the rest of Guadalcanal. No urban households were sampled in the province of Rennell & Bellona (Figure 1).

2.4 Data collection

Data collection was carried out by teams consisting of Solomon Islands Ministry of Health and Medical Services (MHMS) WaSH staff, volunteers and enumerators. Data collection was supported by Demographic Health Survey (DHS) enumerators to use existing experience and help ensure that teams maintain quality when collecting data in the field. Data collection was conducted in English and Pidgin, and managed by the UNICEF Solomon Islands WaSH Officer in oversight of a project manager and coordinator. The data collection in the rural EAs was conducted from November 2015 to January 2016. Data collection in urban EAs took place from

August to September 2017. Ethical clearance was obtained from the University of North Carolina at Chapel Hill (study #16-0842 and #17-3194).

2.5 Data analysis

We calculated descriptive statistics and conducted Chi-Square tests to describe the magnitude of the disparity between urban and rural areas. Frequencies for all variables of interest are reported, as well as means and/or quintiles for numeric variables. STATA 15 was used to clean and analyze the data. The significance level was set at p-value ≤ 0.05 (Supplementary Files 1-3).

We contextualized the domestic urban and rural sanitation infrastructure results in terms of their assumed resilience, vulnerability and adaptability that is *assumed* since the infrastructure has yet to be adapted and thus resilience cannot be measured, using the global assessment of resilience of water and sanitation technology framework provided by Howard et al. (2010) and Howard & Bartram (2010) (Table 2). The analysis considered two extreme weather event scenarios, including i) increased rainfall and ii) decreased rainfall as outlined by the mentioned framework.

Table 2

3 Results: Vulnerability and adaptability of sanitation infrastructure in the Solomon Islands

3.1 Sanitation services under an increased rainfall scenario

Overall the majority of households had low assumed resilience (high vulnerability and low adaptability, see Table 2) under an increased rainfall scenario, due to the high rate of open defecation (56%). Of the households with access to a sanitation service, the majority had a medium-high assumed resilience (medium vulnerability and high adaptability), since they had access to pit latrines (20%). A marked difference in the assumed resilience of sanitation services between urban and rural areas was apparent (Figure 4).

Figure 4

The majority of urban households' sanitation had medium to medium-high assumed resilience to increased rainfall due to high septic tank (44%) and pit latrine (26%) ownership. Most rural households had low assumed resilience due to high rates of open defecation (80%). Rural households with a sanitation service (20%), had primarily medium-high assumed resilience under an increased rainfall scenario because they had pit latrines (17%).

3.2 Sanitation services under a decreased rainfall scenario

Under a decreased rainfall scenario, overall, the majority of the study population in the Solomon Islands had a low assumed resilience (high vulnerability and low adaptability, see Table 2) due to the high rate of open defecation (56%) (Figure 5). The majority of households that had a sanitation service had a medium-high assumed resilience due to the high rate of pit latrine ownership (20%). Similar to under an increased rainfall scenario, the resilience differed between urban and rural households.

Figure 5

In urban areas, majority of households had medium-to-high assumed resilience under decreased rainfall scenarios, since they had septic tanks (44%) which have a medium assumed resilience (medium vulnerability and medium adaptability) or pit latrines (26%) which have a high resilience (low vulnerability and high adaptability). Most rural households, had low assumed resilience, due to the high rate of open defecation (81%). However, of the rural households that had a sanitation facility the majority had high resilience because they had pit latrines (17%).

4 Discussion

We contextualized our results concerning urban and rural sanitation services with assumed resilience, vulnerability and assumed adaptability to two extreme weather event scenarios – decreased rainfall and increased rainfall - using the global assessment of resilience of water and sanitation technology framework provided by Howard et al. (2010) and Howard & Bartram (2010) .

4.1 The value of our sanitation baseline data: comparison to regional estimates

PICs lag behind international trends in sanitation and hygiene development, experiencing some of the lowest levels of global improvement in WaSH (WHO & UNICEF 2017). Of all PICs, the Solomon Islands has among the lowest access to basic sanitation services according to our baseline (36% overall), and according to previous JMP estimates (31% overall, WHO & UNICEF 2017), only exceeding Papua New Guinea (19% overall, WHO & UNICEF 2017). The Solomon Islands also has the highest rate of households without access to a sanitation service in the region, according to our baseline (55% overall), and according to previous JMP estimates (41%) (Table 3).

Table 3

Our analysis is comparable to the official JMP statistics for basic and limited sanitation services.

Comparing our baseline results of households with unimproved services (6% urban; 6% rural) to the average numbers according to the JMP (23% overall; 0% urban; 29% rural) (WHO & UNICEF 2017), reveals that the sanitation situation in the surveyed households may be worse than presented in official country-wide numbers. This is reflected also in a higher rate of households without access to a sanitation service in our survey (55% overall; 18% urban; 80% rural) relative to the numbers reported by JMP (41% overall; 9% urban; 50% rural) (WHO & UNICEF 2017).

The differences between our findings and official statistics such as JMP estimates may be explained by various factors including our sampling and data collection methods, our large sample size (n = 2,667), small differences in the definition of sanitation services which were more precise and WASH-focused than the Demography and Health Surveys (DHS), Multiple Indicator Cluster Surveys (MICs) and censuses that usually form the basis of JMP estimates. While we randomly surveyed urban and rural household representing the entire country, MICS surveys cover only a specific population group in or a certain geographical area within a country, and censuses DHSs are nationally-representative household surveys that provide data for a wide range population, health and nutrition indicators, thus often lacking detail . Additionally, differences in estimates may be explained by the methods used to determine the JMP estimates. JMP derives their estimates by applying an ordinary least squares linear regression to multiple data points from different surveys and across multiple years to determine estimates for the country (WHO & UNICEF 2017) for each year, whereas we present the data from the households we surveyed at a single time point from a cross-sectional survey without interpolations or any derivations.

4.2 Vulnerability and adaptability of sanitation infrastructure: resilient to extreme weather events?

The Solomon Islands is vulnerable to climate change (Shields et al. 2016) and frequently experiences extreme weather events. Tropical cyclones, resulting flooding, as well as drought are on top of the list. In the South Pacific, increases in annual precipitation may exceed 20% (Perkins et al. 2012, IPCC 2014). Heavy rainfalls are likely to become more frequent and intense, potentially causing more frequent flash floods (Hadwen et al. 2015). Additionally, while average rainfall is projected to increase in the rainy season, the Solomon Islands and other PICs will also experience a decrease of rainfall in the dry season rainfall (Hadwen et al. 2015, Connell 2015). A range of models also indicate tropical cyclones will become more intense, with larger peak winds speeds (Hadwen et al., 2015).

We discuss the resilience of current sanitation infrastructure in urban and rural areas in the Solomon Islands under two extreme weather scenarios – decreased rainfall and increased rainfall (Howard et al. 2010, Howard & Bartram 2010).

4.2.1 Sanitation under a decreased rainfall scenario

In environments that are getting drier and where groundwater levels decline, the impact on sanitation services may be a mix of both positive and negative impacts.

Of the rural households with sanitation access in the Solomon Islands, the majority use pit latrines (17%). This type of sanitation infrastructure will make rural households relatively climate-resilient during periods of decreased rainfall, as pit latrines continue to function properly despite reduced water availability (Luh et al. 2017). While a pour-flush pit latrine is less resilient than dry pit latrines due to the water required to transport the solids and the increased susceptibility to clogging with water scarcity, they may be readily adapted to deal with issues under a decreased rainfall scenario (Luh et al. 2017, Sherpa et al. 2014). Additionally, a drying climate may actually have positive effects on on-site sanitation, as lowering groundwater levels reduce pollution risks from pit latrines (Howard & Bartram 2010, Howard et al. 2006), and groundwater flooding of pits may be less frequent (Sherpa et al. 2014, Luh et al. 2017).

One quarter of urban households also use pit latrines (26%) and will be similarly resilient to the effects of a drying, increasingly water-scarce environment like their rural counterparts. However, the majority (52%) of remaining urban households use septic tanks or sewer systems. While, similar to pit latrines, lower groundwater levels can also reduce the risk of seasonal flooding of septic tanks (Howard & Bartram 2010, Luh et al. 2017), in drying environments, the volumes of water required to keep a septic tank functioning may be difficult to sustain increasing the risk of clogging and making it difficult for mechanical removal of sludge (Sherpa et al. 2014). Declining water availability will also pose major threats to sewer systems as obtaining sufficient quantities of water to transport solids through the pipes will be problematic (Howard & Bartram 2010, Luh et al. 2017). In an expert assessment of the resilience of water and sanitation systems to climate-related hazards (Luh et al. 2017), one expert cited an example of a drought in Zimbabwe where residents were instructed to only flush their toilets on the hour, otherwise not enough liquid would be available to carry the solids through the piped network.

To make urban sanitation more resilient in a drying environment, the Solomon Islands will require a shift towards modifications of septic tanks and sewers that require less water for flushing and carriage. This may include reducing water used for septic systems and using manual emptying with adequate protective measures (Sherpa et al., 2014). Additionally, households could convert their conventional sewage connections to solids-free sewage[1], which can be better adapted to drying climate conditions since there is no minimum flow velocity and less chance of clogging (Sherpa et al. 2014, Tilley et al. 2014). However, converting to solids-free sewage will require a high capital investment and as a result may hinder the Solomon Island's adaptive capacity to improve the resilience of these systems.

4.2.2 Sanitation under an increased rainfall scenario

In 2014, heavy rains from a tropical depression, which later became a cyclone, caused severe flooding that affected over 50,000 people, displaced over 10,000 people and severely damaged and destroyed buildings and infrastructure, including sanitation, in the Solomon Islands, particularly in the capital Honiara (Reliefweb 2014). The catastrophic floods showed that with rainfall increases or where there is a shift to higher intensity events, the effect on sanitation services may be seriously adverse in both rural and urban areas.

In rural areas, where the primary form of sanitation among households that have access to a sanitation facility is pit latrines (17%), the primary concern is flooding due to rising groundwater levels (Sherpa et al. 2014, Howard & Bartram 2010, Luh et al. 2017). Intense flooding can lead to overflowing, contamination of drinking water sources and widespread faecal spillage into the environment (Howard et al. 2010). Pit latrines may be readily adapted to prevent flooding by elevating them above ground and creating watertight chambers (Uddin et al. 2013, Sherpa et al. 2014). These adaptations are typically paired with urine-diversion and the replacement of one pit with two shallower pits that can be alternated to facilitate proper retention time for the degradation of faecal material (Tilley et al. 2014, Uddin et al. 2013). However community-led total sanitation (CLTS), which is the official sanitation policy in the Solomon Islands, does not dictate construction of watertight raised pit latrines. Therefore, to increase resilience it will be important

[1] A solids-free sewer is a network of small-diameter pipes that transports pre-treated and solids-free wastewater (such as septic tank effluent). It can be installed at a shallow depth and does not require a minimum wastewater flow or slope to function.

to shift pit latrine design policy towards technologies that are more flood-resilient. This may require greater household investment and possibly subsidies.

In urban areas, the primary form of sanitation is a mixture of pit latrines (26%) and septic tanks (44%). In the expert assessment of the resilience of sanitation systems to climate-related hazards (Luh et al. 2017), septic tanks and pit latrines were scored similarly. However, Howard et al. (2016) considered pit latrines more resilient than septic tanks because pit latrines could be more readily adapted, as discussed above. Urban households with pit latrines may adapt their sanitation facilities similar to their rural counterparts, as raised water-tight pit latrines are also suitable in densely populated areas (Tilley et al. 2014). Septic tanks, similarly face issues due to flooding (Sherpa et al. 2014, Luh et al. 2017). Septic tanks can also suffer from backflow of waste into houses, and drain fields of septic tanks represent a highly significant source of environmental contamination if flooded (Sherpa et al. 2014). While septic tanks are technically designed to be watertight, this may not necessarily be the case for all septic tanks constructed in low and middle income countries. If the septic tanks are not currently watertight they could be modified using materials such as sealed blocks or formed concrete (Uddin et al. 2013, Tilley et al. 2014). They may also be fitted with non-return valves to prevent backflow into houses (Luh et al. 2017) and french drains[2] to divert water away from the drain field (Sherpa et al. 2014, Mara 1996). Additionally, in urban areas currently only 7% of households are connected to sewerage systems in the Solomon Islands. If connection rates increased, these systems will be highly vulnerable to greater rainfall and flooding events, particularly if combined or modified sewers are used (Howard & Bartram 2010, Howard et al. 2016, Luh et al. 2017). Making these systems resilient will require a substantial investment in sewage treatment protected from flooding with the installation of dykes. It will also require protecting sewers from damage during floods, such as the simplified sewer networks that were successfully constructed in India to withstand flooding (Sherpa et al. 2014). However all of these adaptive measures are considerable investments,

[2] A French drain is a ditch lined with gravel with an embedded pipe that can carry water away from any designated surface area.

requiring wide coordination among households, urban planners, and the government and as a result may hinder the Solomon Island's capacity to adapt.

4.2.3 Open defecation under two extreme rainfall scenarios

Although open defecation is not a sanitation technology, and as a result may not be "adapted" to extreme weather events, it poses a sanitation behaviour practiced by a marked proportion of households in the Solomon Islands. If the rates remain high this practice will pose varying threats under the two extreme weather scenarios presented in this paper.

Health hazards associated with open defecation may not be exacerbated under a decreased rainfall scenario unless a drying environment is also paired with short intense rainfall episodes (Luh et al. 2017). With short intense rainfall episodes faecal material may be easily transported and contaminate safe water sources and domestic environments. Additionally, reduced water availability may also spur an increase in open defecation practices, as flush toilets may stop functioning and because inadequate water supply may limit hygienic sanitation practices such as anal cleansing (Sherpa et al. 2014). Colin (2009) and World Bank (2011) similarly reported that inadequate water supply for hygienic sanitation practices hindered the adaptation of sanitation facilities in Bangladesh and India. Therefore, as households are encouraged to adopt and to use sanitation facilities, they should be encouraged to construct sanitation facilities that do not require water, thus increasing their resilience. However, this may prove difficult and require carefully constructed behaviour change messaging, since as a CLTS case study in the Solomon Islands reported the local understanding is that "proper sanitation requires water" (Ranking 2012).

While rural households with pit latrine ownership may be somewhat more resilient to increased rainfall as compared to urban households, as long as rates of open defecation remain high, increased rainfall will result in increased mixing and spreading of faecal material from open defecation throughout communities, likely increasing contamination of drinking water sources (Coulliette et al. 2009). Conversely increased rainfall may threaten access to open defecation sites since they are typically located far from the home (Coffey et al. 2014). This could encourage households with access to sanitation facilities to use them at a higher rate and motivate households without sanitation facilities to construct them. Households should be encouraged to build latrines that are adapted to floods. Urine diverting toilets with raised watertight chambers would function well in both drying and flood-prone areas.

4.3 Limitations

One limitation of this study lies in the cross-sectional design of the surveys, which could not account for varying service levels at different points of time, e.g. according to seasonality. The rural and urban baselines were planned based on different data collection designs, and data were collected at different times (Anthonj et al. 2018, Shields et al. 2017), which may limit the validity of our analyses. In the multi-linguistic context of the Solomon Islands, it is likely that some questions and answers of the survey were lost in translation.

Different geographical areas are potentially at different 'risk' when it comes to sanitation and hygiene (under)supply (Anthonj et al. 2018, Shields et al. 2017), and their vulnerability, adaptability and resilience to extreme weather events. This does not only apply to the highly diverse different islands within the country, but also to urban versus peri-urban areas, and to houses with different tenure and land rights, e.g. in informal settlements (Schrecongost et al. 2015). Our urban WaSH baseline treated urban areas as homogenous and did not consider differences and discrepancies between formal and informal settlements, or urban and peri-urban areas. Both would have allowed for a more detailed picture and analysis in a country where settlements underlie great dynamics in terms of their population growth and movement.

The rural WaSH baseline included neither socioeconomic data, nor data on where different individual family members defecate, or whether the pit or septic tank ever filled up. These would have been important variables to include in the analyses, that could have helped disentangle explanations for the differences in sanitation services. Moreover, the rural survey was conducted during the holiday season, a time during which many people who normally live in Honiara (the capital of the Solomon Islands) go back to their home villages. It is possible that some respondents surveyed were not full-time residents of rural areas, thus lacking some information on and/or misperceiving the sanitation situation (Anthonj et al. 2018, Shields et al. 2017).

Despite these limitations, the results of this study can be assumed to apply in similar PIC and SIDS settings.

5 Conclusions and recommendations for improving climate-resilient sanitation programming

This study examined the resilience of current sanitation services in the Solomon Islands under extreme weather events such as flooding and drought, both of which are commonly observed in the country and the region. It is the first paper, to the authors' knowledge, that has analyzed the climate resilience of sanitation services in a Pacific Island country or small island developing state.

Research on WaSH in SIDS has been scarce. In such complex settings, sanitation, along with drinking water, hygiene, and waste management, need to be better addressed in order to achieve *healthy* long-term development. However, global action and research still lags behind the necessary efforts to achieve SDG 6.

This study shows that climate resilience of sanitation infrastructure needs to be explicitly recognized and addressed by stakeholders, because "one size" does *not* fit all (Bain et al. 2014, (UN-Habitat 2012, White et al. 2008).

As the first detailed nationally representative cross-sectional sanitation study to examine climate resilience in rural and urban areas in the Solomon Islands, the results of this paper inform national WaSH policy, strategic planning and programming by the Solomon Islands Government and stakeholders.

At present, the Government of the Solomon Islands through the MHMS approaches sanitation with a "one size" fits all approach, and exclusively through CLTS. Despite their increasing frequency, the impact of climate change and extreme weather events on infrastructure are not considered. Recommendations for improving climate-resilient sanitation programming in the Solomon Islands therefore include:

- Explicitly considering the impact of climate change and extreme events on infrastructure and add this into the strategic WaSH plan. This will require going beyond the current CLTS policy, including contextualized health messaging, behaviour change interventions, and financial assistance programs to overcome supply chain barriers in rural areas
- CLTS programming in the Solomon Islands should incorporate flood-resistant latrine design, particularly raised water-tight pits, in the light of the country's risk to extreme weather events.
- As sanitation access expands, households should be encouraged to adopt sanitation technologies that are not reliant on large quantities of water, including pit latrines or toilet designs that require less water to function.
- In urban areas, with increases in population and wealth it is likely sewage connections will expand. City planners, households, and governments should consider solids-free sewage design which is more climate resilient since it does not require a minimum flow velocity, important under drought conditions, and can be made to withstand flooding events. In addition, authorities need to create systems to properly treat sewage and prevent environmental contamination.

Recommendations for improving WaSH-related monitoring and evaluation and research not only in the Solomon Islands, but throughout PICs and other SIDS vulnerable to climate change include:

- Accounting for issues related to climate resilience for water and sanitation services in future monitoring in SIDS, and especially in PICs such as the Solomon Islands
- Adapting respective monitoring tools to the prevailing situation and challenges in order for governments to collect all information needed to adapt WaSH infrastructure in the light of increasing frequency and unpredictability of such events.

- Aligning WaSH monitoring with the proposed JMP core and expanded survey questions for the SDGs to allow countries to track progress towards the achievement of the SDGs, and compare performance to other countries.
- Reporting excreta disposal for the highest level of sanitation service – safely managed.

Future studies should investigate inter-urban / peri-urban differences in terms of sanitation and resilience to extreme weather events, as well as solid waste and sewerage management in more detail, in order to identify areas in which improvements and interventions are needed.

References

Albert, S., Leon, J.X., Grinham, A.R., Church, J.A., Gibbes, B.R., Woodroffe, C.D., 2016. Interactions between sea-level rise and wave exposure on reef island dynamics in the Solomon Islands. Environmental Research Letters 11, 054011. https://doi.org/10.1088/1748-9326/11/5/054011.

Anthonj, C., Falkenberg, T. 2019. Thirst World? Linking Water and Health in the Context of Development. In: Foley, Ronan, Kearns, Robin, Kistemann, Thomas, Wheeler, Ben (eds.) Blue Space, Health and Wellbeing: Hydrophilia Unbounded. Routledge. 167-189.

Anthonj, C., Fleming, L., Shields, K.F., Cronk, R., 2018. Solomon Islands Urban Water, Sanitation and Hygiene Baseline Report. Government of the Solomon Islands. Honiara. 61 pages. (unpublished report)

Anthonj, C., Beskow, S., Dornelles, F., Fushita, A.T., et al., 2014. Water in Urban areas: Building Future Knowledge to integrate Land Use, Ecosystem Services and Human Health. Science Policy Report. Brazilian Academy of Sciences, German National Academy of Sciences Leopoldina, German Young Academy. Rio de Janeiro, Brazil; Berlin, Halle, Germany. 29 pages.

Australian Government Department of Foreign Affairs and Trade (DFAT), 2018. Solomon Islands country brief. Available at https://dfat.gov.au/geo/solomon-islands/Pages/solomon-islands-country-brief.aspx.

Bain, R.E.S., Wright, J.A., Christenson, E., Bartram, J.K., 2014. Rural:urban inequalities in post 2015 targets and indicators for drinking water. Sci. Total Environ 490, 509-513. https://doi.org/10.1016/j.scitotenv.2014.05.007.

Bartram, J., Cairncross, S., 2010. Hygiene, sanitation, and water: Forgotten foundations of health. PLoS Med. 7, e1000367. https://doi.org/10.1371/journal.pmed.1000367.

Black, R.E., Morris, S.S., Bryce, J., 2003. Where and why are 10 million children dying every year? Lancet 2003, 361, 2226–2234. https://doi.org/10.1016/S0140-6736(03)13779-8.

Bukenya, G.B., Nwokolo, N., 1990. Transient risk factors for acute childhood diarrhoea in an urban community of Papua New Guinea. Transactions of The Royal Society of Tropical Medicine and Hygiene 84(6), 857–860. https://doi.org/10.1016/0035-9203(90)90107-P.

Carpenter, C., Jones, P., 2004. An overview of integrated water resources management in Pacific Island Countries: A national and regional assessment. Status Report for GWP – Integrated Water Resources Management (IWRM), prepared for the South Pacific Applied GeoScience Commission (SOPAC). SOPAC Miscellaneous Report 554, 66 pp.

Clarke, M., Feeny, S., Donnelly, J., 2014. Water, Sanitation and Hygiene Interventions in the Pacific: Defining, Assessing and Improving 'Sustainability'. The European Journal of Development Research 26(5), 692–706. https://doi.org/10.1057/ejdr.2013.67.

Clasen, T.F., Bostoen, K., Schmidt, W.P., Boisson, S., Fung, ICH, Jenkins, M.W., Scott, B., Sugden, S., Cairncross, S., 2010. Interventions to improve disposal of human excreta for preventing diarrhoea. Cochrane Database of Systematic Reviews 6. Art. No.: CD007180. https://doi.org/10.1002/14651858.CD007180.pub2.

Coffey, D., Gupta, A., Hathi, P., Khurana, N., Spears, D., Srivastav, N., Vyas, S., 2014. Revealed Preference for Open Defecation Evidence from a New Survey in Rural North India. Research Institute for Compassionate Economics, SQUAT Working Paper 1. https://riceinstitute.org/research/revealed-preference-for-open-defecation-evidence-from-a-new-survey-in-rural-north-india-longer-working-paper/.

Colin J., 2009. Sustainability and equity aspects of total sanitation programmes: A study of recent Water-Aid supported programmes in Bangladesh. WaterAid.

Connell, J., 2015. Vulnerable Islands: Climate Change, Tectonic Change, and Changing Livelihoods in the Western Pacific. The Contemporary Pacific 27(1), 1-36. https://doi.org/10.1353/cp.2015.0014.

Coulliette, A.D., Money, E.S., Serre, M.L., Noble, R.T., 2009. Space/Time Analysis of Fecal Pollution and Rainfall in an Eastern North Carolina Estuary. Environmental Science and Technology 43(10), 3728–3735. https://doi.org/10.1021/es803183f.

Cronin, A.A., Sebayang, S.K., Torlesse, H., Nandy, R., 2016. Association of Safe Disposal of Child Feces and Reported Diarrhea in Indonesia: Need for Stronger Focus on a Neglected Risk. Int J Environ Res Public Health 13(3), 310. https://doi.org/10.3390/ijerph13030310.

Fewtrell, L., Kaufmann, R.B., Kay, D., Enanoria, W., Haller, L., Colford, J.M. 2005. Water, sanitation, and hygiene interventions to reduce diarrhoea in less developed countries: a systematic review and meta-analysis. Lancet Infect. Dis., 5 (1), 42-52. https://doi.org/10.1016/S1473-3099(04)01253-8.

Greenwell, J., McCool, J., Kool, J., Salusalu, M., 2013. Typhoid fever: hurdles to adequate hand washing for disease prevention among the population of a peri-urban informal settlement in Fiji. Western Pacific Surveillance and Response Journal 4(1), 41–45. https://doi.org/10.5365/wpsar.2012.3.4.006.

Haberkorn, G., 2008. Pacific Islands' Population and Development: Facts, Figures and Follies. New Zealand Population Review 33/34, 95-127.

Hadwen, W.L., Powell, B., MacDonald, M.C., Elliott, M., Chan, T., Gernjak, W., Aalbersberg, W.G.L. 2015. Putting WASH in the water cycle: climate change, water resources and the future of water, sanitation and hygiene challenges in Pacific Island Countries. J. Water San. Hyg. Dev. 05.2, 183-191. https://doi.org/10.2166/washdev.2015.133.

World Bank, 2011. Long term sustainability of improved sanitation in rural Bangladesh. Water and Sanitation Program research brief. Washington, DC: World Bank. http://documents.worldbank.org/curated/en/713051468014437835/Long-term-sustainability-of-improved-sanitation-in-rural-Bangladesh.

Howard, G., Carlow, R., Macdonald, A., Bartram, J. 2016. Climate Change and Water and Sanitation: Likely Impacts and Emerging Trends for Action. Annual Review of Environmental Resources 41, 253-276. https://doi.org/10.1146/annurev-environ-110615-085856.

Howard, G., Charles, K., Pond, K., Brookshaw, A., Hossain, R., Bartram, J. 2010. Securing 2020 vision for 2030: climate change and ensuring resilience in water and sanitation services. Jounral of Water and Climate Change 1(1), 2-16. https://doi.org/10.2166/wcc.2010.105b.

Howard, G., Bartram, J., 2010. Vision 2030. The resilience of water supply and sanitation in the face of climate change. Technical report. WHO/HSE/WSH/10.0.1 World Health Organization. 47 pages.

Intergovernmental Panel on Climate Change (IPCC), 2014. Climate change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 688.

Luh, J., Royster, S., Sebastian, D., Ojomo, E., Bartram, J. 2017. Expert assessment of the resilience of drinking water and sanitation systems to climate-related hazards. Science of the Total Environment 592, 334-344. https://doi.org/10.1016/j.scitotenv.2017.03.084.

MacDonald, C.M., Chan, T., Elliott, M., Kearton, A., Shields, K.F., Barrington, D.J., Souter, R.T., Powell, B.R., Bartram, J., Hadwen, W.L., 2017. Temporal and thematic trends in water, sanitation and hygiene (WaSH) research in Pacific Island Countries: a systematic review. Water San. Hyg. Dev. 07.3, 352-368, https://doi.org/10.2166/washdev.2017.021.

Mara, D. D., 1996. Low-Cost Urban Sanitation. Wiley, Chichester, UK. pp. 63-65.

Merson, M.H., Martin, W.T., Craig, J.P., Morris, G.K., Blake, P.A., Craun, G.F., Feeley, J.C., Camacho, J.C., Gangarosa, E.J., 1977. Cholera on Guam, 1974. Epidemiologic findings and isolation of non toxinogenic strains. American Journal of Epidemiology 105(4), 349-61. https://doi.org/10.1093/oxfordjournals.aje.a112393.

Ministry of Environment, Climate Change, Disaster Management and Meteorology (MECDM). 2018. Solomon Islands Climate in Brief. Government of the Solomon Islands. Honiara. Available at http://www.met.gov.sb/solomon-islands-climate-in-brief.

Ministry of Environment, Climate Change, Disaster Management and Meteorology (MECDM). 2012. Solomon Islands National Climate Change Policy 2012-2017. Government of the Solomon Islands. Honiara. 53 p. Available at http://www.gcca.eu/sites/default/files/catherine.paul/si_climate_change_policy.pdf.

Ministry of Health and Medical Services. 2014. The Solomon Islands Rural Water Supply, Sanitation and Hygiene Policy. Solomon Islands: Ministry of Health and Medical Services.

Morita, T., Godfrey, S., George, C.M., 2016. Systematic review of evidence on the effectiveness of safe child faeces disposal interventions. Tropical Medicine & International Health 21(11. https://doi.org/10.1111/tmi.12773.

Mosley, L.M., Sharp, D.S., Singh, S., 2004. Effects of a Tropical Cyclone on the Drinking-water Quality of a Remote Pacific Island. Disasters 28 (4), 393-405. https://doi.org/10.1111/j.0361-3666.2004.00266.x.

Perkins, S.E., Irving, D.B., Brown, J.R., Power, S.B., Moise, A.F., Colman, R.A., Smith, I., 2012. CMIP3 ensemble climate projections over the western tropical Pacific based on model skill. Climate Research 51(1), 35–58. https://doi.org/10.3354/cr01046.

Reliefweb, 2014. Solomon Islands: Flash Floods - Apr 2014. https://reliefweb.int/disaster/fl-2014-000045-slb.

Schrecongost, A., Wong, K., Dutton, P., Blackett, I., 2015. Delivering Water and Sanitation to Melanesian Informal Settlements. Water (Australia). 5 pp.

Schrecongost, A., Wong, K., 2015. Unsettled: Water and Sanitation in Urban Settlement Communities of the Pacific. Retrieved from https://openknowledge.worldbank.org/bitstream/handle/10986/23336/Full0report.pdf?sequence=1&isAllowed=y.

Schwarz, A.-M., Béné, C., Bennett, G., Boso, D., Hilly, Z., Paul, C., Posala, R., Sibiti, S., Andrew, N., 2011. Vulnerability and resilience of remote rural communities to shocks and global changes: Empirical analysis from Solomon Islands. Global Environmental Change 21(3), 1128-1140. https://doi.org/10.1016/j.gloenvcha.2011.04.011.

Sherpa, A., Zurbrügg, C., Koottatep, T., & Cissé, G., 2014. Vulnerability and adaptability of sanitation systems to climate change. Journal of Water and Climate Change. 5. https://doi.org/10.2166/wcc.2014.003.

Shields, K.F., Kearton, A., Hadwen,W.L., MacDonald, M.C., Chan, T.U., Elliott, M., Bartram, J., 2016. Strengthening the Enabling Environment for Climate Resilient WaSH in the Solomon Islands. Brisbane, Australia.

Shields, K.F., Cronk, R. D., Abebe, L., 2017. Solomon Islands Rural Water, Sanitation and Hygiene Baseline Report. Government of the Solomon Islands. Honiara. 74 pages. (unpublished report)

Solomon Islands Government, 2009. 2009 Population & Housing Census. Report on Migration and Urbanisation. Honiara, Solomon Islands.

Tilley, E., Ulrich, L., Lüthi, C., Reymond, Ph. and Zurbrügg, C., 2014. Compendium of Sanitation Systems and Technologies. 2nd Revised Edition. Swiss Federal Institute of Aquatic Science and Technology (Eawag). Dübendorf, Switzerland

Uddin, S.M., Ronteltap, M., van Lier, J.B., 2013. Assessment of urine diverting dehydrating toilets as a flood-resilient and affordable sanitation technology in the context of Bangladesh. Journal of Water, Sanitation and Hygiene for Development 3(2), 87-95. https://doi.org/10.2166/washdev.2013.113.

United Nations, 2010. Resolution 64/292. The human right to water and sanitation. http://www.un.org/en/ga/search/view_doc.asp?symbol=A/RES/64/292.

United Nations General Assembly, Transforming Our World: The 2030 Agenda for Sustainable Development. 21 October 2015. A/RES/70/1. Available online: http://www.refworld.org/docid/57b6e3e44.html.

UN-Habitat. 2012. Solomon Islands: National Urban Profile. United Nations Human Settlements Programme. UN-Habitat. Nairobi, Kenya.

White, I., Falkland, T., Metutera, T., Katatia, M., Abete-Reema, T., 2008. Safe water for people in low, small Island Pacific Nations: The rural-urban dilemma. Development 51 (2), 282-287. http://dx.doi.org/10.1057/dev.2008.18.

WHO/UNICEF, 2017. Progress on Drinking Water, Sanitation and Hygiene – 2017 Update and SDG Baselines. United Nations Children's Fund & World Health Organization.

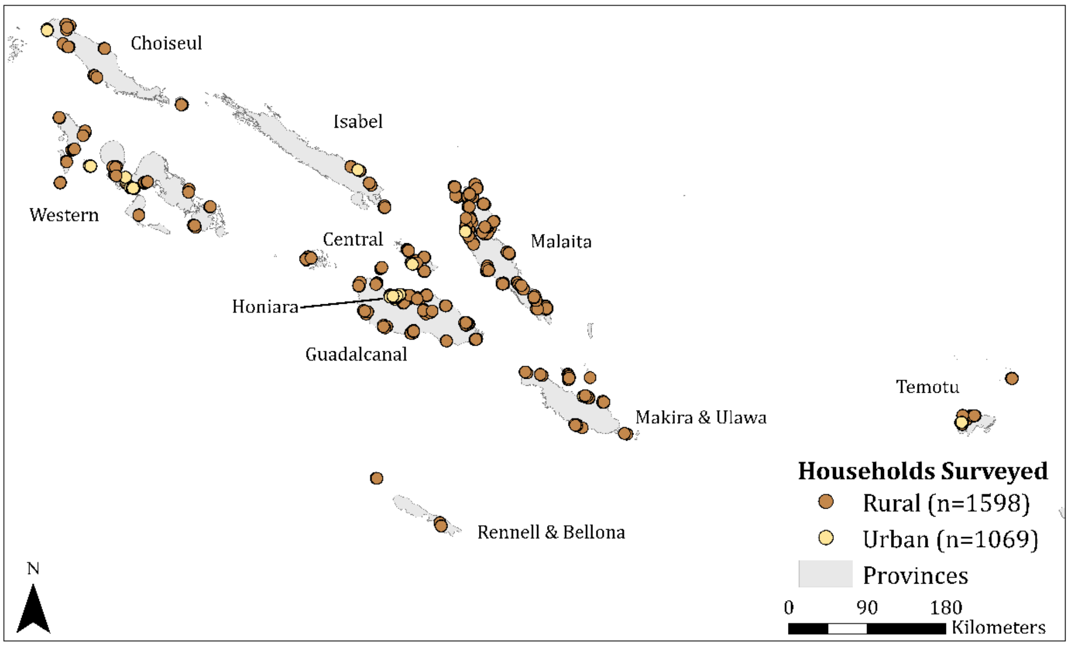


Figure 1: Rural and Urban Households in the Solomon Islands included in this Study

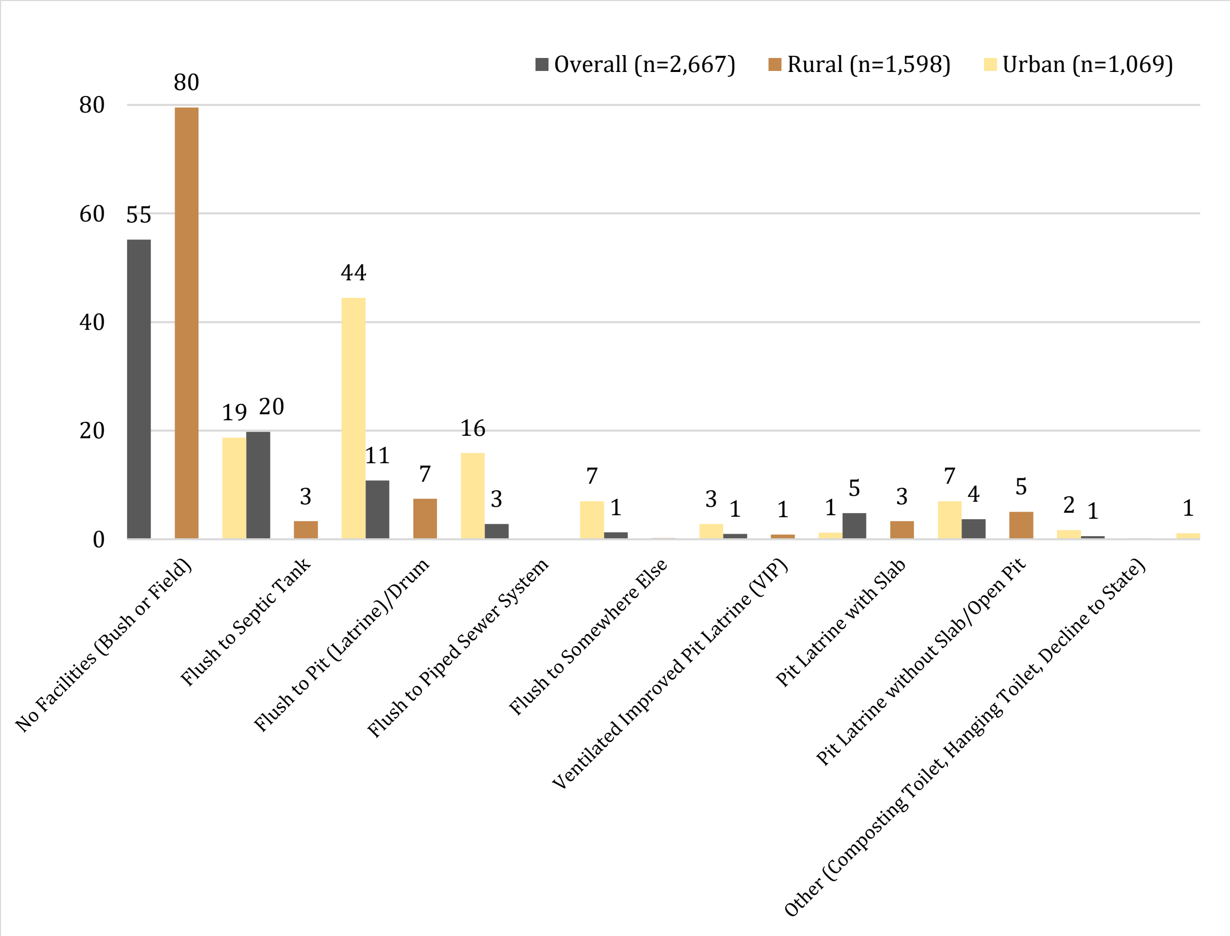
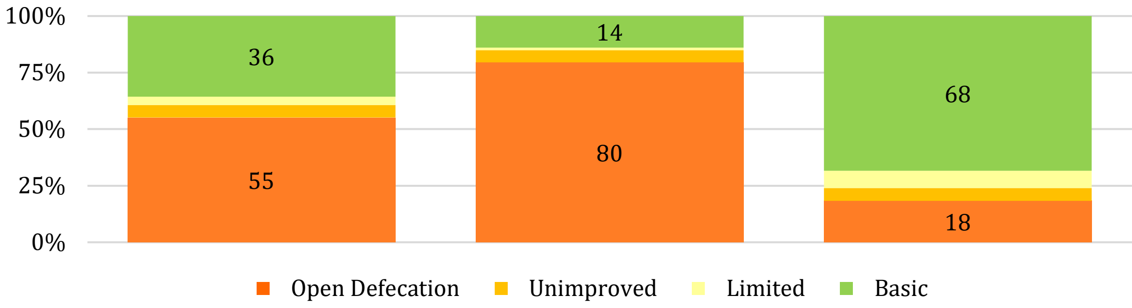


Figure 2: Type of Domestic Sanitation Facility [%]

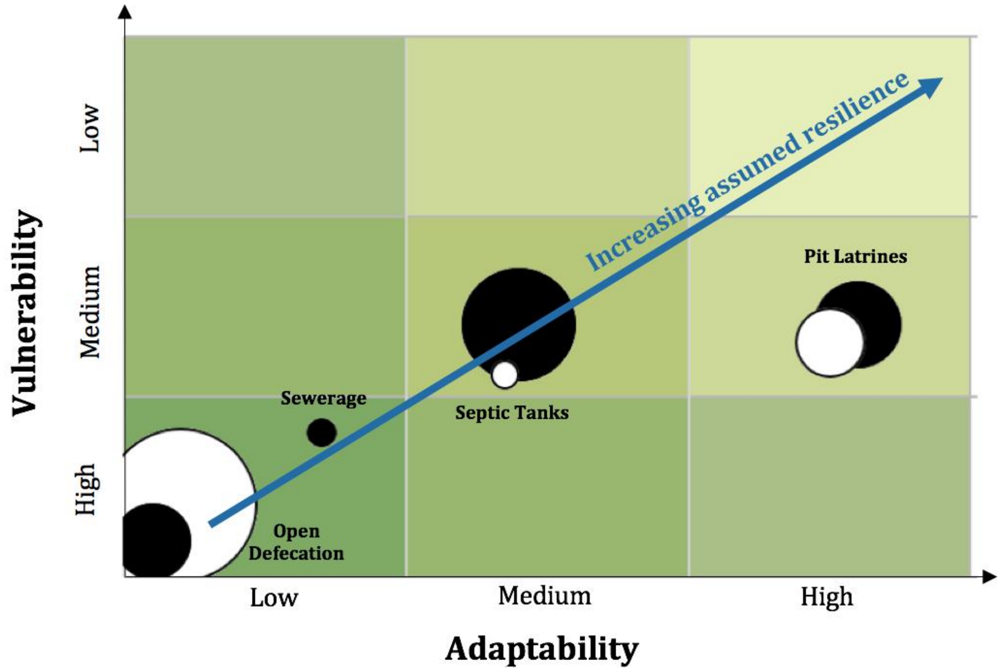
Overall (n=2,661)	Rural (n=1,597)	Urban (n=1,062)



Sanitation Service Levels in Households in the Solomon Islands [%]

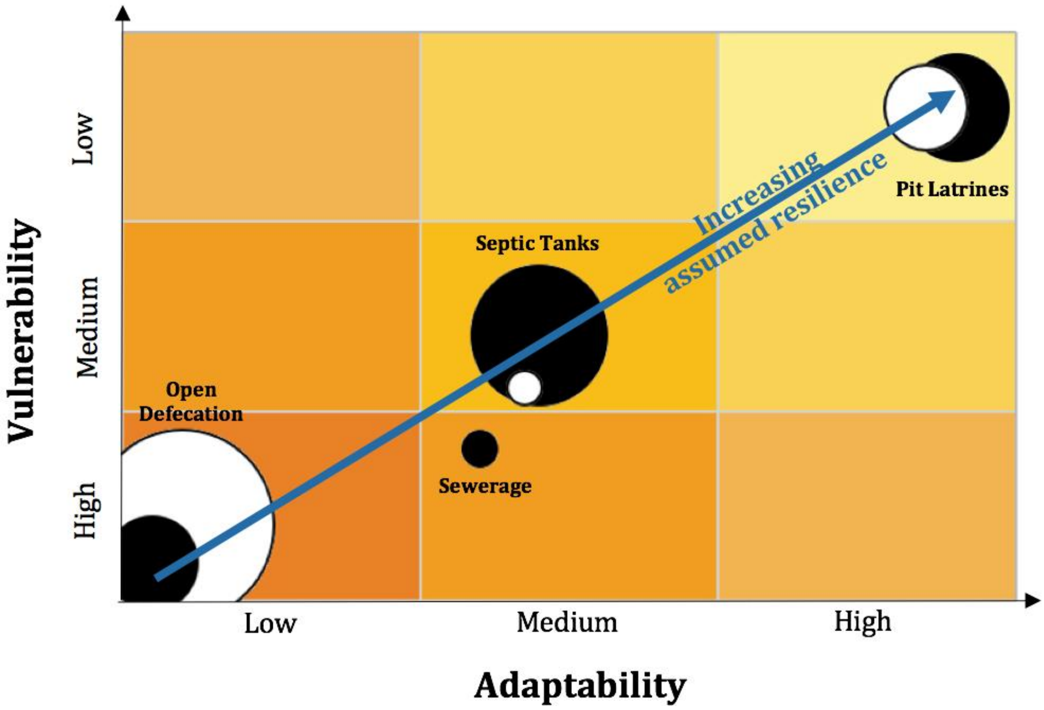
Sanitation Service Levels: Basic: Use of improved facilities which are not shared with other households. Limited: Use of improved facilities shared between two or more households. Unimproved: Use of pit latrines without a slab or platform, hanging latrines or bucket latrines. Open defecation: Disposal of human faeces in fields, forests, bushes, open bodies of water, beaches and other open spaces or with solid waste. Definitions based on WHO & UNICEF 2017.

Figure 3: Sanitation Service Levels in the Solomon Islands [%]



Black circles represent urban households. White circles represent rural households. The circle size reflects the proportion of households that use each type of sanitation, with increasing size of circles reflecting a larger proportion of households.

Figure 4: Resilience of Sanitation in Urban and Rural Households in the Solomon Islands under a Scenario of Increased Rainfall



Black circles represent urban households. White circles represent rural households. The circle size reflects the proportion of households that use each type of sanitation, with increasing size of circles reflecting a larger proportion of households.

Figure 5: Resilience of Sanitation in Urban and Rural Households in the Solomon Islands under a Scenario of Decreased Rainfall

Table 1: Composition of Households in the Solomon Islands

	Overall (n=2,661)				Rural (n=1,597)				Urban (n=1,062)			
	Mean	Median	Min	Max	Mean	Median	Min	Max	Mean	Median	Min	Max
Adults (>15 years)	4	3	1	53	4	3	1	53	5	4	1	53
Children (5-14 years)	2	1	0	20	2	1	0	20	1	1	0	10
Children (<4 years)	1	1	0	11	1	1	0	11	1	1	0	10
Household Size	7	6	1	56	6	6	1	56	7	6	1	55

Table 2: Resilience of different sanitation types under different extreme weather scenarios

Sanitation Technology	Decreased Rainfall		Increased Rainfall	
	Vulnerability	Adaptability	Vulnerability	Adaptability
Flush Toilet with Sewers	High	Low	High	Medium
Flush Toilet with Septic Tank	Medium	Medium	Medium	Medium
Pit Latrine	Low	High	Medium	High

Adapted from Howard & Bartram (2010)

Table 3: Comparing our Results (UNICEF Pacific, 2016-2018) to WHO/UNICEF JMP Estimates (2015) on Sanitation Services in Urban and Rural Areas in the Solomon Islands, and to Small Island Developing States in the SDG Region Oceania (%)

Country	Basic Sanitation Service			Limited Sanitation Service			Unimproved Sanitation			Open Defecation (%)		
Solomon Islands	Overall	Urban	Rural	Overall	Urban	Rural	Overall	Urban	Rural	Overall	Urban	Rural
UNICEF Pacific results (2016-2018)*	**35.7**	**68.4**	**13.9**	**3.7**	**7.5**	**1.1**	**5.5**	**5.7**	**5.5**	**55.1**	**18.4**	**79.5**
JMP estimates (2015)	31.3	76.1	18.4	5.1	14.9	2.3	22.6	0.0	29.1	41.1	9.0	50.3
Other Small Island Developing States in the SDG Region Oceania (JMP estimates 2015), assorted from highest to lowest coverage												
New Caledonia	100	NA	NA	0	NA	NA	0	NA	NA	0	NA	NA
Palau	100	100	100	0	0.0	0.0	0	0.0	0.0	0	0.0	0.0
Wallis & Futuna	99.1	NA	99.1	0	NA	0.0	0	NA	0.0	0.9	NA	0.9
Cook Islands	97.6	NA	NA	0	NA	NA	2.4	NA	NA	0	NA	NA
Fr. Polynesia	96.9	NA	NA	0	NA	NA	3.1	NA	NA	0	NA	NA
Niue	96.8	NA	NA	0	NA	NA	3.2	NA	NA	0	NA	NA
Samoa	96.6	98.1	96.3	0	0.0	0.0	3.3	1.6	3.6	0.1	0.2	0.1
Fiji	95.7	96.1	95.2	3.8	3.6	3.9	0.4	0.2	0.7	0.1	0.1	0.2
Tonga	93.5	96.6	92.5	1.0	0.9	1.1	5.5	2.5	6.4	0	0.0	0.0
Tokelau	93.1	NA	93.1	4.7	NA	4.7	2.3	NA	2.3	0	NA	0.0
Tuvalu	91.4	91.7	91.0	0.1	0.1	0.0	1.4	2.4	0.0	7.1	5.8	9.0
Guam	90.4	NA	NA	8.8	NA	NA	0.1	NA	NA	0.7	NA	NA
Marshall Islands	86.9	94.8	65.9	0.1	0.1	0.1	2.4	1.6	4.5	10.6	3.5	29.5
Mariana Islands	78.8	NA	NA	18.7	NA	NA	2.2	NA	NA	0.2	NA	NA
SIDS	67.9	80.2	48.1	10.3	11.9	7.7	14.8	5.6	29.7	7.0	2.3	14.6
Nauru	65.6	65.6	NA	30.7	30.7	NA	1.1	1.1	NA	2.6	2.6	NA
American Samoa	62.2	NA	NA	36.4	NA	NA	1.4	NA	NA	0	NA	NA
Vanuatu	53.	61.4	50.7	17.9	31.8	13.0	26.9	5.7	34.4	1.7	1.1	1.9
Kiribati	39.8	49.5	32.1	8.4	13.7	4.1	17.2	21.7	13.7	34.6	15.2	50.1
Papua New Guinea	18.6	55.2	13.1	3.4	8.6	2.6	65.1	32.3	70.0	12.9	3.8	14.3

* Result from our UNICEF Pacific & The Water Institute baseline data collection in rural and urban areas (2016-2018).
All other data was extracted from WHO & UNICEF JMP (2015) at https://washdata.org/data.
NA stands for not applicable and applies for countries where no data was collected.

Supplementary File 1: Domestic Sanitation in the Solomon Islands [%]

	Overall (n=2,667)	Rural (n=1,598)	Urban (n=1,069)	*p*-value difference urban vs. rural
Household Access to a Sanitation Facility				<0.0001
No	55.06	79.54	18.73	
Yes	44.94	20.46	81.27	
Permission to *View Sanitation Facility*				<0.0001
No Permission	8.33	2.69	16.76	
No Sanitation Facility	56.08	79.60	20.88	
Yes	35.60	17.71	62.36	
Type of Sanitation Facility (reported)				<0.0001
No Facilities (Bush or Field)	55.18	79.54	18.73	
Flush to Septic Tank	19.80	3.32	44.48	
Flush to Pit (Latrine)/Drum	10.84	7.45	15.92	
Flush To Piped Sewer System	2.81	0.00	7.02	
Flush to Somewhere Else	0.98	0.25	2.06	
Ventilated Improved Pit Latrine (VIP)	1.01	0.88	1.22	
Pit Latrine with Slab	4.80	3.32	7.02	
Composting Toilet	0.04	0.06	0.00	
Pit Latrine without Slab/Open Pit	3.71	5.07	1.69	
Bucket	0.08	0.06	0.09	
Hanging Toilet or Hanging Latrine	0.38	0.06	0.84	
Decline to State	0.08	0.00	0.19	
Flush to don't know where	0.30	0.00	0.75	
Type of Sanitation Facility (observed)				<0.0001
Flush to Septic Tank	45.42	16.96	57.51	
Flush to Pit (Latrine)/Drum	25.18	43.46	17.42	
Flush to Somewhere Else	1.48	0.35	1.95	
Flush to Piped Sewer System	5.80	0.00	8.26	
Ventilated Improved Pit Latrine (VIP)	3.79	5.30	3.15	
Pit Latrine with Slab	10.54	15.90	8.26	
Pit Latrine without Slab/Open Pit	6.32	17.67	1.50	
Hanging Toilet or Hanging Latrine	0.95	0.35	1.20	
Flush to don't know where	0.42	0.00	0.60	
Location of Sanitation Facility				<0.0001
Own Household Toilet (Inside House)	46.73	27.30	54.95	
Own Household Toilet (Outside)	42.62	62.06	34.38	
Shared Toilet (Public Used by Everyone)	0.84	1.06	0.75	
Shared Toilet (Multiple Households)	9.81	9.57	9.91	
Privacy of Sanitation Facility (observed)				<0.0001
Not Private: Can be Heard	3.93	3.67	4.05	
Not Private: Can be Seen	6.85	14.98	2.85	
Not Private: Can be Seen And Heard	5.54	14.07	1.35	
Yes, Privacy is Protected	83.69	67.28	91.74	
Cleanliness of Sanitation Facility (observed)				<0.0001
Clean: No Faecal Matter, Flies, Smell	65.36	51.68	72.07	
Not Clean: Some Faecal Matter, Flies, Smell	28.30	38.23	23.42	
Dirt/Filth: Lots Faecal Matter, Flies, Smell	6.34	10.09	4.50	
Happiness with Usage of Sanitation Facility				<0.0001
Very Happy	50.55	41.28	55.11	
Neither Happy nor Unhappy	34.64	36.70	33.63	
Unhappy	14.80	22.02	11.26	
Usage of Sanitation Facility by All Household Members (including children)				<0.0001
Decline to State	0.50	1.22	0.15	
Everyone Uses the Toilet	92.45	87.46	94.89	
Some Defecate in the Open	7.05	11.31	4.95	
Difficulty of Household Member in Accessing Sanitation Facility				0.368
No	94.77	95.41	94.57	
Yes	3.73	3.98	3.65	
Don't know	0.79	0.61	0.84	
Decline to state	0.72	0.00	0.94	
Sanitation Service Level				<0.0001

Open Defecation	55.12	79.52	18.38	
Unimproved	5.53	5.45	5.66	
Limited	3.69	1.13	7.54	
Basic	35.67	13.90	68.43	
Diarrhea1 Disease in 3 Days preceding Survey				0.918
No People in HH had Diarrhea	81.81	81.73	81.95	
At Least 1 Person in HH had Diarrhea	18.19	18.27	18.05	

Supplementary File 2: Disposal of Child Faeces in the Solomon Islands [%]

	Overall (n=2,667)	Rural (n=1,598)	Urban (n=1,069)	*p*-value difference urban vs. rural
Buried/Burned				0.006
No	82.19	79.98	85.46	
Yes	17.81	20.02	14.54	
Child Uses Toilet/Latrine				0.044
No	80.04	78.33	82.61	
Yes	19.96	21.67	17.39	
Don't know				<0.0001
No	95.77	92.96	100.00	
Yes	4.23	7.04	0.00	
Drain/Ditch/Pit				0.003
No	93.66	92.08	95.98	
Yes	6.34	7.92	4.02	
Open/Bush				<0.0001
No	91.35	87.07	97.82	
Yes	8.65	12.93	2.18	
Ocean/Beach/Seashore				<0.0001
No	66.36	55.51	84.09	
Yes	33.64	44.49	15.91	
Put / Rinsed into Toilet/Latrine				<0.0001
No	86.79	96.62	73.10	
Yes	13.21	3.38	26.90	
Put in River/Stream				0.012
No	95.67	96.85	94.00	
Yes	4.33	3.15	6.00	
Thrown into Rubbish				<0.0001
No	86.69	90.94	80.59	
Yes	13.31	9.06	19.41	